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Electrical Power System Architectures for Military & Commercial Vehicular Applications

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Abstract:

Future military and commercial vehicular electrical system architecture proposals are presented in this paper. These are necessary to meet the growing demands of electrical loads, such as electrification of traditional mechanical loads, in-vehicle computer and multimedia systems, among others. In this paper, future electrical system architecture proposals using 42-volt dc and 120/230 volt 60 Hz ac are discussed. In many instances military can afford to develop technologies earlier than the commercial sector. Later these developments can lead to commercial applications. In addition, cost and technical issues are examined for these high voltage systems. These issues arise due to new requirements of load, battery, ignition systems, fuses, connectors, and wiring harnesses.

Keywords: 42 volt system, automotive electronics, vehicular power system, power electronics, vehicular electrical system architecture, more electric vehicle (MEV), LAV, HMMWV, wiring harness, alternator.

Introduction:

The electrical power system architecture in vehicles has followed a trend so as to accommodate the progressively higher power needs over the years. It started initially with a 6-volt system (7 volts when fully charged) and then transitioned to 12 volts (14 volts when fully charged) in the mid 1950's due to increased electrical power requirements. Since then it has been so (at 14 volt level) until now. Lately, there has been a significant increase in power levels due to the use of electronic equipments (cellular phones, and the multimedia in the vehicles), and the application of power electronics based electrical actuators allowing the replacement of the existing hydraulic, pneumatic, or other mechanical systems. From the present full load power demand in the commercial passenger automobile of around 1.5-2.0 Kw, a level of around 3 Kw or 3.5 Kw (or to even 5 Kw or more) can be well expected in the next 5 years [1-2].

The needs in the military (and combat) vehicles, though somewhat different, are following a similar trend. In particular, the silent watch power usage in military involves extensive amount of electrical and electronic auxiliary devices with minimum electromagnetic and infrared (heat) signatures and the engine stopped. This requires high electric energy storage either in battery, or fuel cell type silent generation. Currently such demands are met through auxiliary power units run by small generators. The military vehicles presently use mainly a 28 volt architecture. The power demands are relatively high, depending on the vehicle in question, such as tank, LAV (Light Armored Vehicle), and HMMWV (High Mobility Multi-purpose Wheeled Vehicle). To address the increasing electrical load demands, the automotive and defense industry are currently planning to implement a 42-volt dc architecture in vehicles. This will lead to component size and weight reduction. In this paper a 42-volt dc and 120/230 volt ac vehicular architectures and issues arising from the application of these voltage are discussed.

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Existing 28 volt architecture in military applications:

Today's military vehicles with 28-volt system, use two 14-volt lead acid batteries as storage and to support the electrical loads, provide power for starting, and help reducing the alternator voltage ripples. A belt-driven 28-volt alternator typically supplies about 5 KW electrical loads e.g. in a LAV (Light Armored Vehicle).

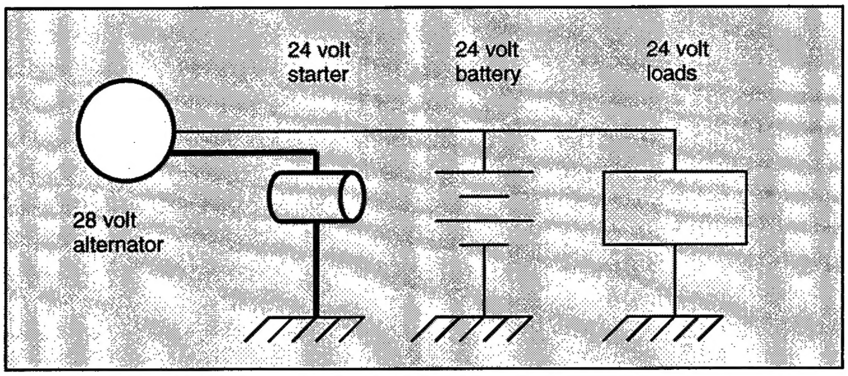

Figure 1. 28 volt electrical system architecture for military applications

For commercial automobile, the architecture is exactly as in Figure 1, with the 28 volt replaced with 14 volt, and 24 volt replaced with 12 volts respectively, and typical (total) loads are of the order of 1.5 to 2 KW. It is anticipated that future electrical loads for both military and commercial applications will, in all likelihood, double or triple within the next 5 years [1].

Future architectures in military applications:

In this section future architectures using 42 volt dc, 120 volt ac, and 230 volt ac are discussed, the latter in order to conform with the utility industry standards allowing dual usage of technology and components.

In addition, instead of a sudden switchover to a new architecture, there has been proposal to use dual voltages where initially the old and the new architectures will coexist simultaneously.

- 42 volt system: A mature technology exists in power electronics, which is applicable to both commercial and the military applications as well, and is essential for the 42 volts dc system architecture [2-5]. Power electronics will be needed for the conversion of the variable-speed alternator voltage to a constant dc voltage. It should be noted that the 42-volt electrical system efficiency will be 1.5 times more compared to the 28 volt system, and the wiring harness size will be 1.5 times lighter in weight when a 28 volt system is changed to 42 volt system. Other advantages of 42 volts with respect to both the commercial and the military applications are the use of electrically operated components instead of continuously running hydraulic/mechanical components (which are parasitic in nature), e.g. power steering, brake, and electrical valve control systems for engines and transmissions. It is believed that these changes, along with the use of a regenerative starter-generator system, will lead to fuel savings of about 10 to 15%.

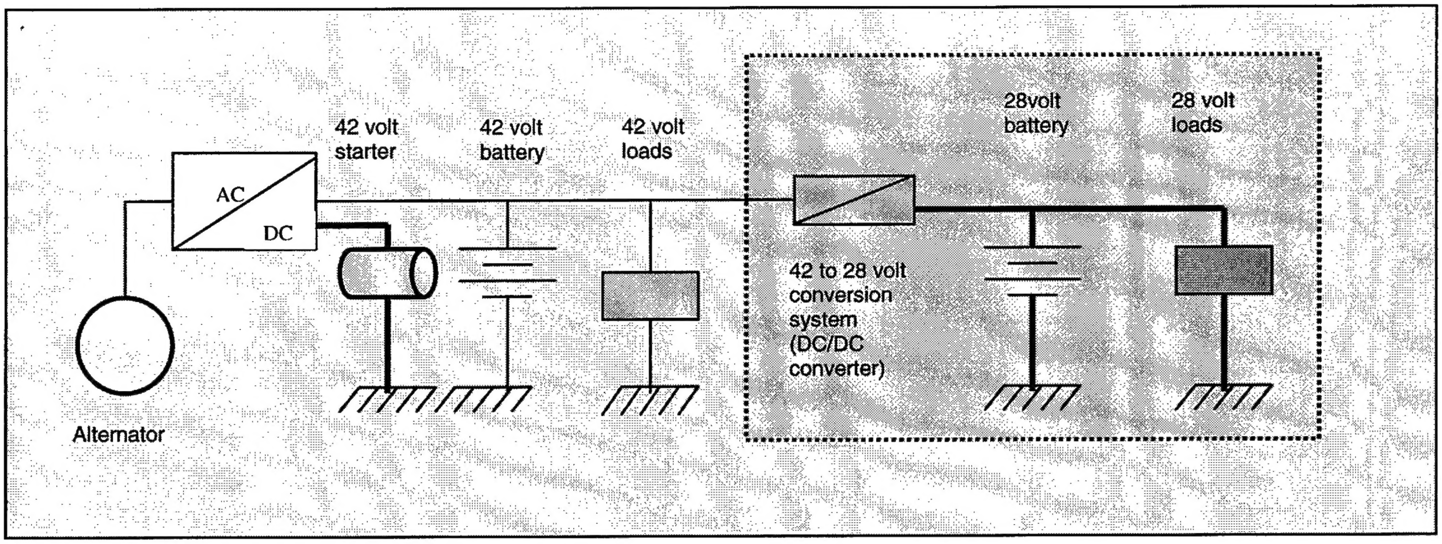

Figure 2. 42/28 volt dual voltage system architecture

Figure 2. shows the 42 volt dc electrical power system architecture with dual voltage. The area shown within dotted border can be phased-out (eliminated completely) when the supplier infra-structure and customer concerns are properly addressed, thus leading to a single completely 42 volt system. The disadvantages of the 42 volt system are that the life of the filament based incandescent bulbs used in the vehicle will be shorter, because filaments with higher voltage and same power will be thinner. This can be addressed by introducing gas discharge lamps. Other disadvantages relate to load dump issues, high voltage transient spikes, and fire hazards during blowing of fuses, turning off of switches, or breaking of other connections caused due to arcing. For commercial automobile, the architecture is similar, with the 28 volt replaced with 14 volt.

- <u>120/230 volt ac system</u>: Safety has been the main consideration of military/automotive electrical system voltage beyond 42 volts dc. It should be noted that safety considerations are also important in domestic use where 120/230 volt ac is used. It has been shown [6-7] that 3 phase ac

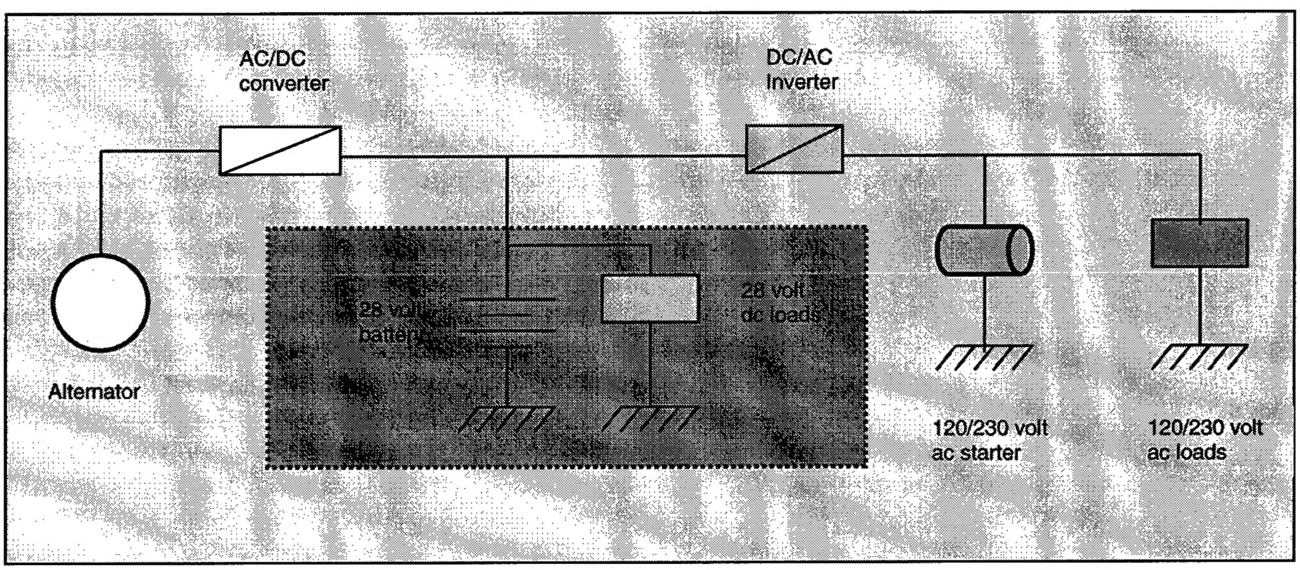

Figure 3. 120 or 230 v ac/28 volt dc dual voltage system architecture

systems are viable for automotive use. The motor loads can be 3-phase ac loads, and the lighting loads can be either single phase ac, or dc, depending on the needs. Advantages of using utility standard voltages is that a complete dual usage of electrical devices with the utility industry can be realized. The issue of arcing, fuses, battery terminals, jump starting mechanism, etc. have to be adequately addressed in this case, however. Some of these may need additional research work in order to meet the vehicular needs.

High Voltage System/Component Issues:

This section provides some insight into the issues associated with transitioning to 42 volt dc and 120/230 volt ac vehicular system architectures:

Battery Systems - More than 90 percent of the present day military/commercial vehicles have one type of battery, the 28 volt (with two 14-volt batteries in series) and a single 14-volt battery respectively. In the following paragraphs, issues pertaining to high voltage batteries required in 42 volt dc architecture are discussed.

For high voltage system the economically viable batteries will most likely be the flooded lead acid battery or the VRLA (valve regulated lead acid) battery. These batteries have been developed by several manufacturers within reasonable cost. The more expensive batteries which are relatively compact and with higher energy density, are the NiMH (nickel metal hydride) and the Li-ion (lithium ion) batteries. The battery design is affected in terms of size and cost depending on whether the starter motor is energized by it or not. If the battery is used for running the starter motor (short time duration high currents), then it will require large electrode plate surface area for cold weather starts, since battery power requirements are dictated by the cold starting requirements. This significantly increases the cost and size of the battery. However, this can be reduced by having an ultracapacitor for the starter, instead of the main battery. In 42 volt system, the battery is charged and discharged frequently at relatively large current. This causes high temperature to be generated within the battery, which reduces battery life. To address this, battery manufacturers have used ultra high-density positive active material, anti-corrosive grid alloy for the positive plate, special AGM separator for high compression, and additives to negative active material [8] with added cost.

Since the battery life is affected by the depth of discharge, and the number of charge-discharge cycles, it is important to have appropriate system level management of the battery and its interfacing components. This implies that an account of charge and discharge is to be maintained and the system should be directed to charge the battery accordingly, thus controlling the pre-set charging and discharging currents. This smart battery management can be easily implemented by incorporating a microprocessor-based module placed on the body of the battery itself.

Further research is needed to make 42 volt battery connectors to be arc and corrosion proof [9]. For military application in particular, the batteries need to be rugged to handle the off road, and high vibration environment.

Lighting system -

Presently two voltages are used for light bulbs, i.e. 12 and 24-volts. If 42 volt (or 36 volt nominal) system is introduced, the filaments will have to thinner, and consequently more fragile. In addition, it should be noted that the bulb life is extremely sensitive to voltage variations. For instance, in the 9007 Major Filament [1], increasing the voltage from 12.8 to 13.4, the bulb life is reduced from 1000 hours to only 300 hours. There are two main techniques to reduce and control the voltage level. These are: (a) DC/DC converter method, (b) the PWM method [1,10]. Other alternatives in lighting system can be the use of HID (High Intensity Discharge) lamps with Xenon lamp, which has excellent

durability since there are no filaments. However it needs a ballast which can be designed easily at 42 volts. The main problem with this lighting system is its high cost [1]. Work is currently undergoing on white high brightness and large area Light Emitting Diodes (LED's), to replace some of the incandescent bulbs. For military applications in particular, the light fixtures must be rugged enough to handle the high vibration, wet, and corrosive environment.

Arcing in120/230 volt ac system -

The issue of arcing in 120/230 volt ac circuitry is more important than 42 volt ac. Arcs arise due to high voltages at the break-point caused by sudden interruption of current. This problem is predominant in inductive circuit containing motors, and solenoids. Extra precautions are needed if the break-point is located in a place where there can be gaseous or other flammable gases. Furthermore, the circuit should be enclosed in vacuum, or packaged in a special non-flammable material. In addition, load dump spikes in high voltage system will be excessive which should be studied further.

Ignition System (Coil on Plug) -

The ignition coils in vehicles are directly mounted on the spark plug and robustly connected to the plug. The 42-V ignition coils use 14 volt coil design because the secondary turns cannot be increased significantly. Hence alternate system methods have to be devised such as feed-forward diode to prevent breakdown of spark plug gap during primary charge.

Figure 4 shows a 42 volt ignition system with a coil-on-plug type ignition coil [11]. However, with 42V system, the coil under-charge produces low-energy spark or no spark, or over-charge causes advanced spark timing, and heat dissipation during excess dwell. These issues require resolution for the successful implementation.

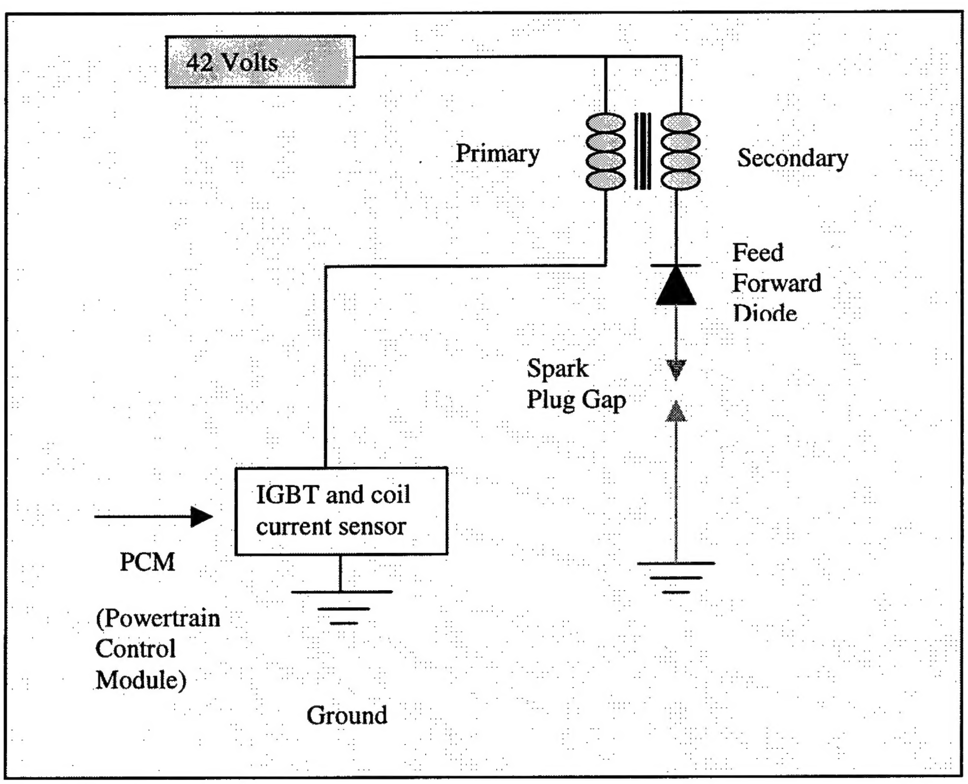

Figure 4. 42 volt ignition system with coil-on-plug.

42 volt dc and 120/230 volt ac system architecture service, diagnostics, and manufacturing issues -

In this section some of the diagnostic and service issues associated with the transition to 42 volt dc and 120/230 volt ac electrical system are indicated.

- Industry standards need to be developed for jump starting vehicles fitted with high voltage batteries.
- There is a potential safety hazard to a service technician and a customer working with high voltage vehicles.
- Special service kits and repair guidelines need to be developed for wiring repairs on a vehicle at higher voltages.
- Wiring identifier standards need to be developed for different voltage circuits.
- Appropriate low and high voltage fuse standards should be developed to prevent interchangeability and damage to vehicle electrical system during service.
- The implementation of a new vehicular architecture normally faces significant bottleneck due to not only technical, but also due to high voltage parts manufacturing and supply infra-structure.

Customer acceptance issues:

The cost and fuel economy are the issues guiding the acceptance of higher voltage electrical system architecture for vehicular applications, which are described in the following paragraphs:

(A) Cost – Items leading to cost increase in the vehicle are conversion of non-electrical items to electrical (change from hydraulic/pneumatic to electrically actuated power steering, brakes, actuators, integrated starter alternator), which are transparent to the user who will more than likely be indifferent to those internal working details.

(B) Consideration of fuel economy – This is an important factor to the customer. The fuel economy will come from several items working together, e.g. reduced size of the wiring harness and weight, regeneration from brakes, starter generator, reduction of parasitic losses etc. Therefore, it is necessary to perform additional research to evaluate the effect of integrating all the above aspects in the vehicle.

It is possible that items A and B above may be conflicting with each other i.e. to get higher fuel economy the cost penalty might increase. This might imply that the first 42-volt vehicles entering the market will be in luxurious vehicle platforms rather than lower end vehicles. For military applications, this does not apply however, since in this case the needs will dictate which technology is warranted.

Conclusions:

This paper discusses the pros and cons of high voltage dc and ac electrical system architectures for both the commercial and the military applications. Military does not necessarily need to follow the exact same path as the automobile industry. In fact, it can take the lead to develop high voltage vehicular technologies earlier than the commercial sector. Military can immediately replace more of its existing mechanical devices with electrical systems (which are difficult to implement in the commercial sector due to regulatory and other mandates). Additional research and studies are needed to address the issues related to high voltage electrical system architectures leading to an optimal system. The cost and fuel economy are the issues guiding the customer acceptance of a higher voltage electrical system architecture for vehicular applications. In particular, fuel economy is of special significance in military systems because it has to transport its own fuel to the site of operation.

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